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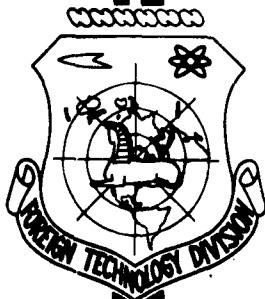
TRANSLATION

NEW APPARATUS TO STUDY THE KINEMATICS OF MOVING OBJECTS

By

V. K. Morgunov

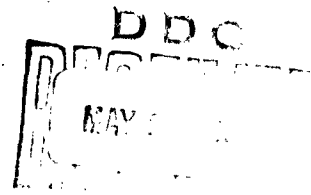
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New Apparatus To Study the Kinematics Of Moving Objects

by

V.K.Morgunov

When conducting scientific investigations it often becomes necessary to determine the kinematic elements of moving objects. And such objects can be a moving ship, a floating ice field, hydrometric floats etc.

The basic data for the obtainment of kinematic elements are movements of objects in the function of time. To fix the step-by-step positions of a moving object at present time are basically used geodetic methods, which offer sufficient accuracy in determining the speed at greater time intervals between the intersection. With an increase in the frequency of intersections there is a rise in relative error of the measured movements, and consequently also in the speeds, on account of the errors due to inaccuracy of sighting the instrument toward the observed point of the object in ratio to its movement. Consequently in the given case the accuracy of the instruments is not brought to full utilization. In many instances geodetic methods are generally unacceptable as result of insufficient frequency of intersections (2-4 intersections per minute).

Consequently, when it becomes necessary to more frequently determine the speed of a moving object motion picture is quite frequently employed. Measuring the displacements of a picture of an object on motion picture film by a definite number of frames, knowing the frequency of the photographing and taking into consideration the scale of the image, is found the law of motion of the object, and then the speed and acceleration as a function of time.

But in many instances motion picture taking does not offer the necessary accu-

rary when investigating the kinematics. Small dimensions of the image on the motion picture films require greater magnification on the screen or under the measuring microscope, which leads to unclearness as result of limited resolving power of the motion picture camera lens and film emulsion, and also its granularity. Unclearness leads to errors and does not allow to reveal small accelerations of the object with necessary accuracy.

Sometimes motion picture taking has to be done under conditions at which the angle between the optical axis of the objective (lens) and the trajectory of motion of the object is considerably different from 90° . To obtain in this case an equiscale condition along the line of motion of the object on the photo it must be transformed, which must be done graphically, which even more reduces the accuracy of results. Phototransformation in the given case is generally very difficult, because it requires a greater number of prints for individual frames.

The accuracy decreases also on account of temperature and shrinkage deformation of the film material. After expiration of a certain time as result of aging and irregular shrinkage of the film it is no longer suitable for measuring processing.

We must also mention the trouble and difficulty in measuring displacements by individual numerous frames.

To eliminate all these deficiencies the author introduced a "photo camera for photographing a moving object" (Patent application No. 127574 dated June 17, 1959). The given apparatus allows to obtain on one glass negative of large form a sequence of images of a moving object, photographed automatically within uniform, preset time intervals.

This apparatus has a series of advantages in comparison with the motion picture camera used for that purpose. The employment of a long focus lens and, consequently, much larger dimensions of photos allow, at all other conditions being equal, to increase the accuracy of measuring. This circumstance, that the step-by-step images of the object are printed on one photo, offers the possibility of making on the photo the

trajectory of motion of the object and reduce the measurement of displacements to measuring the distances between adjacent images of the object, as result of which is obtained a single chain of dimensions, connecting all road increments. This also considerable raises the accuracy and considerably reduces the effort in measuring pre-processing of photos, and when necessary it allows easy phototransformation of pictures. The employment of glass negatives eliminates shrinkage of same with the expiration of time.

1. Arrangement of the apparatus

In fig.1 is given a schematic drawing of apparatus arrangement. On the forward wall of the rigid camera 1 is situated lens 2 with central shutter 3. When photographing the shutter opens automatically within equal time intervals with definite exposure. The shutter is activated by a spring mechanism 4 through cam 5.

In the immediate vicinity in front of the photo plate 6 is situated a light impermeable elastic screen 7 with vertical slot 8, which can be moved along the photo plate by turning handle 9 on the removable panel 10 and then through a flexible roller 11, conical gears 12 and vertical roller 13 on which screen 7 is fitted.

At the top of the apparatus is a looking device, consisting of a forward sighting frame 14 and movable reticule 15. The aiming frame is fastened over the rear junction point of the lens. Movement of the reticule is simultaneous with the movement of slot 8 with the aid of elastic band 16, wound on rollers 17, having identical diameter as rollers 13. Thanks to this arrangement at any given position of the reticule its axis coincides accurately with the axis of the vertical slot.

To record the characteristic moments in the process of photographing or to synchronize with other observations the apparatus is provided with a time marker, consisting of electric light 18 in housing 19. When pressure is applied in the necessary moment against button 20 at the edge of the photo plate is illuminated a spot, equal to the width of the slot.

For photographing the apparatus is set on a tripod so that its optical axis is

perpendicular to the trajectory of motion of the object, otherwise phototransformation of pictures is necessary.

At the moment of photographing is activated a spring mechanism and the shutter takes automatic pictures within equal time intervals. The task of the observer is to move the reticule 15 by turning handle 9 on the dismantlable panel, follow through the looking device the moving object and keep it all the time in the field of vision of the forward sighting frame 14.

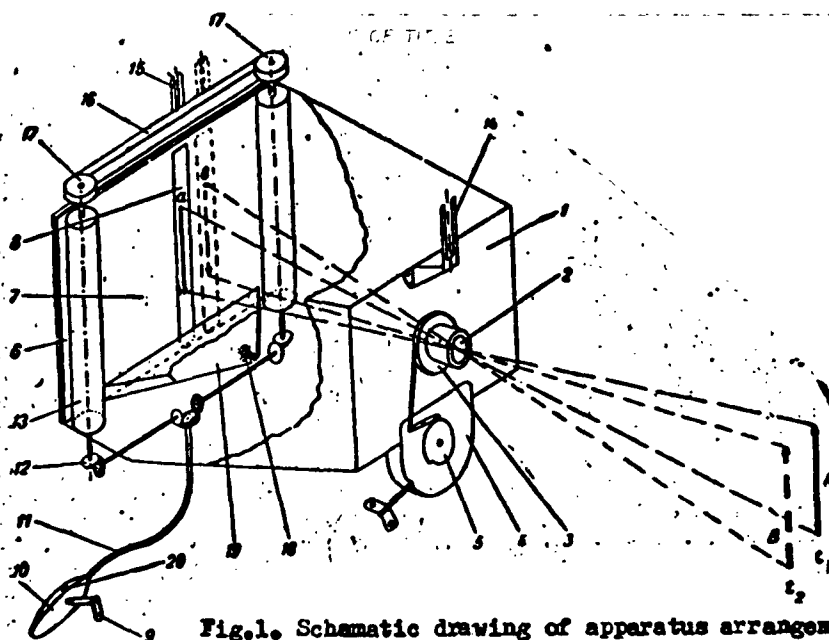


Fig. 1. Schematic drawing of apparatus arrangement

The image of the object on the photo plate will be situated all the time within the boundaries of slot 8 which allows to photograph subsequent images of the object on one photo plate. And so, in the moment t_1 the object occupied position A and in the moment t_2 position B. On the photo plate are obtained corresponding images a and b.

The width of the slot is fixed beforehand according to formula

$$d = \frac{v \cdot F \cdot n}{l \cdot m}$$

where d - width of slot (mm); v - expected least speed, which the object has at the time

of photographing (m/sec; F - focal distance of camera lens (mm), l - distance to photo object (m); n - frequency of photographing (exposures per sec); m - permissible

number of exposures for one and the same place of the photo layer.

The magnitude n depends upon the quality of the photo materials and upon the conditions of background and object illumination. At a dark background and bright object n can be allowed to 5-7, at a bright background and dark object n can equal 2-3. The negatives obtain an optical density, allowing the measurement of displacements.

Measurement of displacements by obtained photos in dependence upon the required accuracy can be made directly on the negatives on a measuring microscope or with the aid of a measuring magnifier with 0.1 mm graduation scale. The speed of the object is determined by formula

$$v_t = \frac{\Delta x \cdot l}{\Delta t \cdot F}$$

where v_t - speed of the object at the moment of time (m/sec); Δx - distance between adjacent images of the object on the photo (mm); Δt - time interval between time exposures of the photo (sec); l - distance to object, measured by optical axis (m); F - focal distance of camera lens (mm).

Having calculated for each moment the magnitude of the speed, it is possible to obtain the change in speed as a function of time, and then go over to acceleration.

2. Example of Employing the Apparatus and Possible Fields of its Application.

At the Ice-Thermal Lab of the Transportation Power Inst. SO of the Academy of Sciences USSR was prepared an experimental sample of the proposed apparatus. The camera had a lens with a focal distance $F = 300$ mm and gives an image on a plate with a dimension of 18 X 24 cm.

The creation of the apparatus was due to the need of raising the accuracy of measuring the rate of motion of ice fields during their actions against bridge supports at the time of spring ice movements on rivers. The obtained data served as basis for calculating the magnitude of dynamic pressure of the ice against the construction by kinematic method of K. N. Korzhavina [1, 2]. For this purpose the camera has been successfully used in many instances along the rivers of Siberia, and to observe the Spring

ice movements in the region of the Bratsk Hydroelectric Power Station which is under construction.

A photo of an ice floe, approaching toward a bridge support, was made from shore or ^{from} an adjoining support. In the latter case the photos were subjected to phototransformation. As reference points on the ice floes were special surveying rods, which launched by a catapult to the floating ice blocks from a distance of up to 180 m and were rammed into the ice.

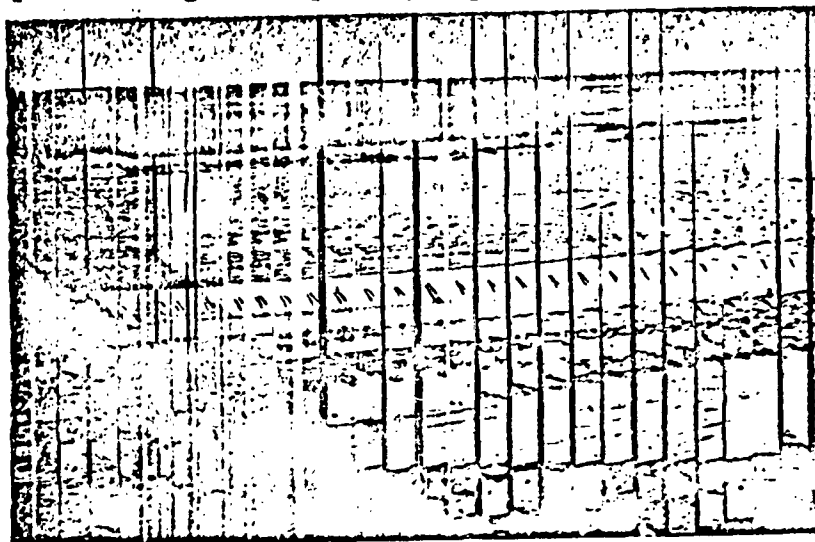
At a distance between camera and line of motion of the surveying stick of 150 m and photographing frequency of one exposure per second the mean square deviation on the rate of motion graphs of the ice floes in the function of time was 0.012 m/sec, which characterizes a sufficiently high accuracy of results, attainable with the aid of the apparatus. Using ordinary geodetic methods or by motion picture photographing it is impossible to obtain such an accuracy.

In fig.2 is given a fragment of a surveying rod photo, obtained with the aid of the apparatus. The photo was made to determine the rate of motion of an ice field during its effect on a bridge support.

The apparatus can also find application in a number of other branches of scientific investigations, particularly to measure surface rate of flow in the case when it changes intensively along the flow and, consequently, and more frequent notchings (markings) of positions of the hydrometric float are necessary, thing which geodetic instruments cannot accomplish. Such an instance may take place for example during hydraulic investigations at hydrotechnical installations. In fig.3 is given a photo of a small ice floe, serving as float when determining the rate of flow. As result of measuring on the photo it is possible to detect even slight changes in the rate of flow along the stream.

At various types of inertia testing of ships comes up the necessity of accurately fixing the change in speed of the ship with respect to the shores. Up until now the

speed of a ship at such investigations was determined by fixing the moment the ship passes through flood-gates, broken down on the shores, or by marking from shore the instantaneous positions of the ship within definite time intervals by means of geodetic instruments [3]. Such methods do not assure necessary accuracy and, what is of special importance, they have a limited notching frequency. Geodetic methods do not at all satisfy the requirements of testing high speed ships, e.g. of the "Rocket" type on underwater wings and others, when to reveal all the details in change in speed frequent notchings are required (1-2 per second).

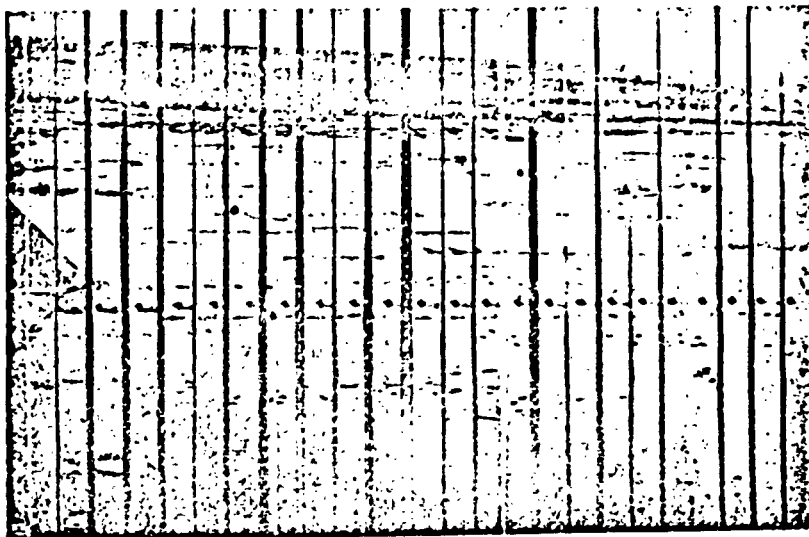


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Fig.2. Photo of surveying rods (two rods in line), placed on moving ice floe. Subsequent positions of the rods along the axis of bridge supports. Photographed at a frequency of one exposure per second.

With the aid of the proposed apparatus it is easy to obtain kinematic elements of tested ship at desired photographing frequency. This extremely simplifies the nature of field investigations, since the photographing can be done by one person.

In 1899-1900 ice investigations were made by the icebreaker "Yermak". During these investigations academivian A.N.Krylov determined the resistance of the ice cover to the movement of the icebreaker by an inertia method. For this was made a motion picture film, approaching the edge of an ice field. By the data of the motion picture



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Fig.3. Photo of floating ice block to determine rate of flow. Photographed at a frequency of one exposure per second.

films was found the speed of the icebreaker in the function of time, which enabled to find acceleration and at known mass of the icebreaker to determine the resistance magnitude of the ice to the movement of the icebreaker [4].

This method, but with a much improved motion picture camera, is used up to this day. But the difficulty of photographic and measuring motion picture films (at low accuracy of obtained results), does not allow to conduct mass observations of this type, so needed for the accumulation of factual data, which appears to be the basis for reasonable planning of ice breakers.

Using the proposed camera for this purpose will enable at inconsiderate loss of time, means and labor to obtain data on the ice load against the icebreaker with greater accuracy. Photographic and metering processing of photos can be done on board the ship and here, within 1.5 to 2 hours, to obtain test results. Thanks to this it appears to be possible to change over from single to mass investigations of various icebreakers and under different conditions of ice floating, involving in this task the engineer-

ing personnel of the ship, and this will allow within a short time to gather a greater number of factual data on ice loads against the body of icebreakers.

The camera can appear to be useful also for the obtainment of kinematic elements of aerial observation objects, particularly the movements of an aircraft at various flight conditions. Taking into consideration the greater speed of aircraft, the photographing can be done with a frequency of several exposures per second. In all these instances the photos appear to be documental material, which can then be subjected to detailed analysis.

At the present day structural design the camera can find application in many other branches of scientific-research operations when observing under natural and laboratory conditions as well.

Conclusions

1. A principally new method is introduced for photographing moving objects with the aid of a special camera. The camera allows to obtain on one photo of large size a sequence of images of a moving object, photographed automatically within equal time intervals.

2. Large dimensions of the photo, as well as the circumstance, that subsequent images of the object are fixed on one photo, allow to greatly increase the accuracy of measurements in comparison to the motion picture film used for that purpose.

3. At a suitable structural design the camera can find application in various branches of scientific-research investigations, as for example, in hydrology, and hydraulics, when testing motional qualities of ships, in aviation etc, in natural and in lab conditions as well.

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Branch of Academy of Sciences USSR
Novosibirsk

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